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Washington Transportation Plan Update

Bottlenecks and Chokepoints

September 13, 2004

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Washington State Department of Transportation

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Executive Summary

Overview

In Washington State, the growth in travel demand has outpaced expansion of transportation system capacity. Additionally there is little evidence that major levels of new investment in highway system capacity will be forthcoming, leaving the state with a backlog of capacity needs now and in the future. This imbalance of demand and capacity occurs in virtually every mode of transportation - at our airports, on our rail lines, and especially on our roadway systems.

The growing demand/capacity imbalance affects citizens' daily lives and almost every sector of economic activity. Commutes to work are time-consuming and often aggravating. Non-work trips, too, must be planned to avoid congestion or with an extra time allowance to account for the lack of reliability in travel times. Freight delivery becomes slower and less reliable. Air pollution is exacerbated by cars and trucks stuck in traffic. Even rural areas that have never seen traffic jams are penalized when highway congestion associated with urban areas interferes with their agricultural products reaching ports and customers.

What is the purpose for this report?

This paper presents background information on congestion, the ways in which bottlenecks and chokepoints affect system efficiency and strategies for addressing these deficiencies. This paper also presents potential policy options for future bottleneck and chokepoint investments and provides examples across the state.

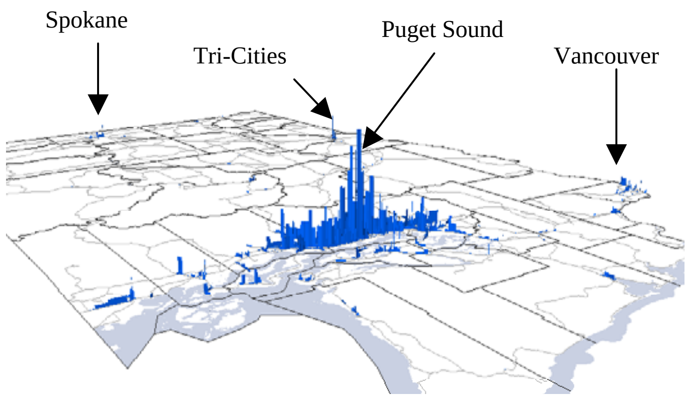
What are the findings?

Washington is Growing
Population and jobs are expected to continue to grow in Washington State. This population growth will translate into substantial increases in travel demand. Washington's workforce is also growing and will continue to a projected 3.9 million by the year 2030. This growth is leading to more travel and compounding delay.

Delay Occurs Mostly in Urban Areas

There is a projected growth in travel that will be concentrated in Puget Sound, Spokane, and Vancouver. Consequently the gap between demand and capacity will grow wider in the future, especially in the major urban areas and high traffic volume corridors. This map illustrates that delay is not evenly distributed across the highways in our state.

Delay is more prevalent in urban areas with the greatest delay found in the Central Puget Sound area. The total delay across the state is estimated to be over 365,000 hours per weekday and represents about $1.6 billion annually in lost time.

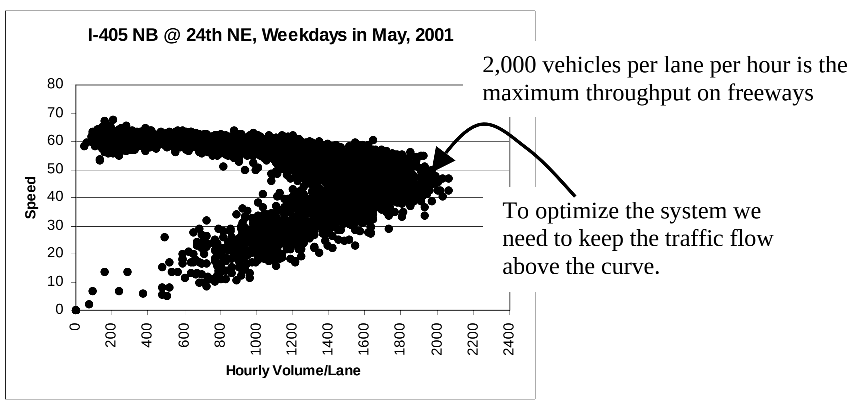


2002 Daily Vehicle Hours of Delay Per Lane Mile

Congestion Actually Reduces Capacity

Congestion in the form of vehicle delay creates inefficiency and has the effect of reducing capacity.

This graph illustrates that although congestion increases and freeway speeds drop below the posted speed limit, the total throughput of the freeway increases until a maximum throughput is reached at about 45 mph. If congestion worsens beyond this point speeds and total throughput drop rapidly. To optimize the efficiency of the freeway system we need to keep the traffic flow on top of the curve.



Speed and Throughput Relationship

Types of Bottlenecks and Chokepoints
Bottlenecks and chokepoints are typically locations on the system where geometry and traffic patterns contribute to congestion. Examples include the Kirkland crawl on I-405, the Southcenter hill climb on I-5, SR-18 between I-5 at Federal Way and SR-167 at Auburn, the Renton S-curves on I-405, US 2 near Monroe and interchanges such as I-5/I-90 in Seattle, I-405/I-90 in Bellevue, and I-5/SR 16 in Tacoma.

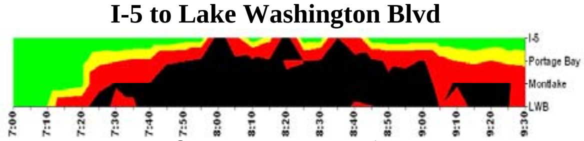
In addition, weather can cause congestion or affect the passability of a roadway creating a bottleneck or chokepoint. Avalanche control on the I-90 Snoqualmie Pass, and roadways closed due to spring thaw restrictions are examples of weather related bottlenecks and chokepoints throughout the state.

Operational and Targeted Capital Investments Can Improve Roadway Productivity
The State currently manages a number of programs to improve the productivity of our highway system. These programs include operational measures and capital investments. Washington State is considered a leader in the use of high occupancy vehicle (HOV) lanes, ramp metering, and signal synchronization.

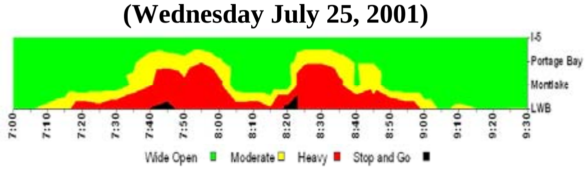
HOV Lanes
HOV lanes increase the efficiency of our system in three ways: by limiting the number of vehicles, overcrowding of the lane is prevented and vehicle throughput is increased, while the higher occupancy rate increases person throughput and creates an incentive to commute via HOV modes.

Ramp Meters
The effect of ramp metering in reducing delay is well documented. These graphs provide a comparison to show the benefits of ramp metering on SR 520. The black/darkest shading shows stop-and-go traffic conditions. Prior to ramp metering, stop-and-go conditions occurred between 7:25 and 9:25 am. After the Ramp metering, most of the stop-and-go condition was eliminated.

SR 520 Eastbound Morning Congestion
I-5 to Lake Washington Blvd



Before Ramp Metering
(Wednesday July 25, 2001)

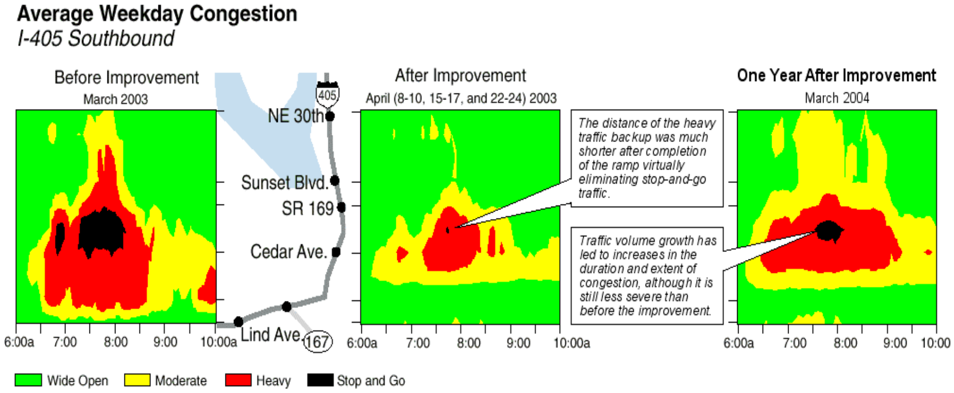


After Ramp Metering
(Thursday September 6, 2001)

Traffic Signal Synchronization
Unsynchronized traffic signals result in that annoying situation of seeming to stop at every light or to wait three short lights to get through an intersection. Although it seems like one of the most fixable bottleneck and chokepoint problems, it is more complex than it appears.

At signalized intersections, green times (the length of time a signal is green) are assigned to specific movements based on the movement's demand at certain time intervals. A surface arterial corridor in urban areas has signalized intersections every few blocks. Signal synchronization's main objective is to coordinate green time for through movements so that most of the through traffic can continue to arrive on "green" at progressive intersections, thereby reducing stop-and-go conditions from intersection to intersection. Like ramp metering for freeways, signal synchronization contributes to arterial operation efficiency similar to the maximum throughput concept on freeways

Fixing Bottlenecks and Chokepoints
Targeted traffic flow improvements can also make a significant difference in system performance. The recently completed I-405/SR 167 Flyover ramp is a good example of one such targeted investment.



Weekday I-405 and SR-167 Flyover Improvement

Prior to the opening of the new ramp stop-and-go conditions occurred weekday mornings between 6:45 and 8:00am. Immediately after the opening of the new ramp, the stop-and-go condition was almost entirely eliminated. In the past year we've seen continued growth in the I-405 mainline volumes as well as the I-405 southbound to SR 167 southbound ramp. While serving higher volumes, the congestion at the interchange area is still considerably lower than the conditions prior to the project. On weekends, both the stop and go traffic and heavy congestion conditions have been essentially eliminated.

What are the recommendations?

The imbalance of demand and capacity on our system causes significant delay that affects the quality of people's lives. This imbalance will only grow as the state experiences increases in population and jobs that result in an increase of travel unmatched by new investment in highway system capacity. WSDOT has been pursuing a practical and balanced strategy, which includes operational improvements (HOV lanes, ramp metering, and signal synchronization) to get the most out of the existing system and restoring lost productivity.

History suggests that, although large-scale corridor improvement plans are desirable as a long-range vision, funding reality says that we need smaller scale affordable capital investments targeting specific traffic restrictions. Targeting capital investments at bottleneck and chokepoint locations would be less expensive than full corridor build-outs, but could deliver significant delay savings and restored productivity. These improvements offer the greatest return on investment.

The Legislature's 2003 Transportation Funding Package is an example in delivering these targeted investments. For example, the package provides $485 million for targeted improvements to I-405 at the worst congested locations: the Kirkland Crawl, through the Wilburton Tunnel approaching I-90 southbound, and at the I-405/SR 167 Interchange vicinity. Similarly, the package targets funding at other locations where traffic flow improvements can make a difference.

Bottleneck and chokepoint investment options could be developed to improve travel for commuters, freight, interregional movement, recreation, and event access. However, new analysis techniques are needed to identify and prioritize the optimal combination of investments.

Introduction: The Crisis of Demand and Capacity

In recent years in Washington State, as well as in other urban locations in the United States, investment in expanded capacity of transportation facilities has not kept pace with the growth in demand placed on transportation systems.[1]

Despite this knowledge, it is difficult to find evidence that suggests there will be increased investments in transportation capacity in the near future. "Bright spots" of investment in new capacity for transportation systems are making only small dents in the overall deficit of capacity needs, excluding the additional needs that continue to both increase and accumulate. The lack of prospects and experience of capacity expansion does not discriminate by transportation mode, but rather the imbalance exists at our airports, on our rail lines and on our highways.

At Our Airports

A 2001 Federal Aviation Administration (FAA) report on airport capacity reported that between 1995 and 2000, delay at the nation's 31 largest airports grew by 90 percent[2]. This delay is a result of capacity constraints, such as inadequate runway or airspace capacity, weather conditions, or a combination of these conditions. After the events of September 11th, 2001, aviation volumes dropped and delay was reduced. However, flight traffic has recovered to previous levels, and delay in the system is again growing.

In Washington State, the existing two runways at Sea-Tac Airport are spaced too close together for two-runway operations during low visibility conditions and the airport experiences capacity-related delay during inclement weather as a result. The third runway project currently under construction will add another runway with enough separation to allow two-runway operations at all times. This improvement will essentially meet Sea-Tac's capacity needs for the next twenty years.

On Our Rail Lines

For the nation's Class I railroads, capacity constraints in major terminals and on mainlines is causing increasing delay in shipments. For Washington State, a recently completed study of mainline rail capacity has indicated that projected volumes of imports, containers and other freight will severely over tax the current mainline capacity in some areas sooner than ten to fifteen years if operational and capital improvements are not made[3].

[1] This trend is well documented. In Washington State, from 1980 to 2000 population was up by 43%, jobs were up by 58%, and VMT was up by 91% while real dollar investment in transportation infrastructure has remained flat. Across the country, frequently cited demonstrations of the problem include increased travel demand, increased delay and reduced travel time reliability.
[2] 2001 FAA ACE Plan: Capacity Benchmarks.
[3] The Washington Public Ports Association (WPPA) Freight Rail Capacity Study
< Hhttp://www.washingtonports.org/Trade/2004 Rail Capacity Study.pdfH>

All passenger trains and nearly 63 freight trains cross the BNSF Columbia River Bridge, a double track swing span bridge that must open several times a day to accommodate waterborne commerce on the Columbia River. A 2003 study found that the current system is severely congested, causing delays to train throughput. Average freight speed was only 12 miles per hour from Tacoma through Portland. This is comparable to delays experienced at the Chicago yard system, a notorious freight bottleneck.

This congestion is primarily caused by lines crossing each other and waiting for other trains. In ten to twenty years, the system will not be able to handle train growth. A list of moderate system improvements to relieve congestion and allow the system to handle projected growth over the next five to ten years was developed in response to this challenge. They include: revising crossovers, increasing speeds, lengthening and/or connecting tracks in several yards[4].

On Our Highways

Over the past two decades, population, employment and travel have grown faster than the transportation supply on highways across the country and in Washington State. As shown in Figure 1, vehicle miles traveled (VMT) in the US has increased 87 percent from 1980 to 2000, while roadway lane miles were up by only 5 percent. As illustrated in Figure 2, travel on Washington roadways is up 91 percent, but lane miles have only increased by 8 percent between 1980 and 2002.

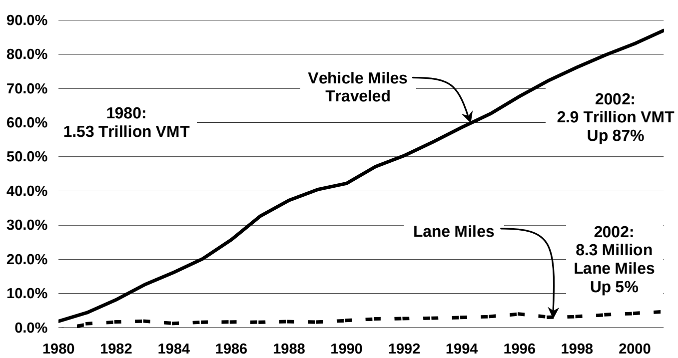


Figure 1. Growth in Vehicle Miles Traveled (VMT) Compared to Lane Miles* United States 1980-2002

*Highway travel estimates are compiled from data by the 50 states and the District of Columbia. Entries have been revised based on updated estimation procedures.
Sources: U.S. Department of Transportation, Federal Highway Administration and Office of Highway Information.

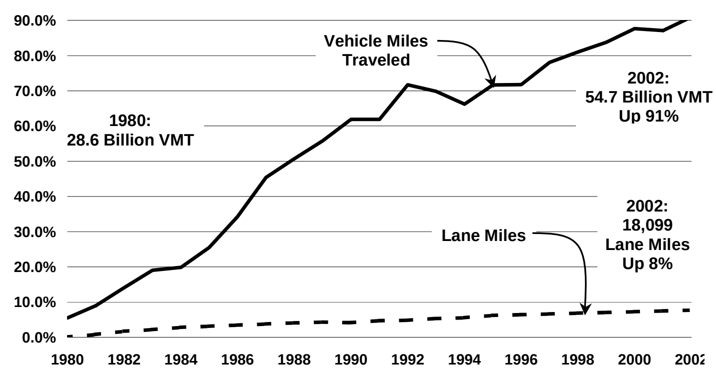


Figure 2. Growth in Vehicle Miles Traveled (VMT)* Compared to Lane Miles Washington 1980-2002**

**Vehicle Miles Traveled (VMT) is Annual Vehicle Miles Traveled (AVMT) in the State of Washington as reported to the Federal Highway Administration in the Annual HPMS submittals.
Source: WSDOT, TDO

Mounting Congestion and Delay

Delay and congestion have become commonplace—especially on arterials and freeways in and around major urban metropolitan areas—as demand continues to increase in the

[4] Portland/Vancouver I-5 Transportation and Trade Partnership (2003)

face of a relatively fixed capacity. The Texas Transportation Institute (TTI) has issued periodic reports documenting the general trends of our nation's increasing congestion and delay.[5]. As illustrated in Figure 3 by the red or dark lines, severe congestion and delay are occurring in metropolitan areas throughout the country. Figure 4 shows that in 2020, delay is expected to increase and spread to an even larger number of highways and urban areas across the nation.

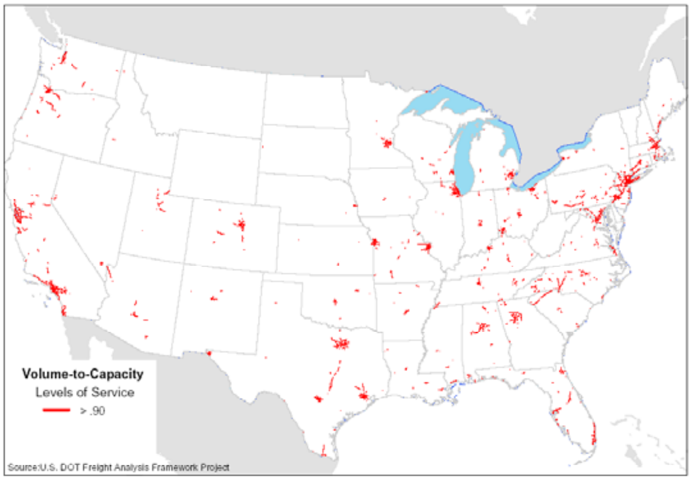


Figure 3. Congested Highways 1998

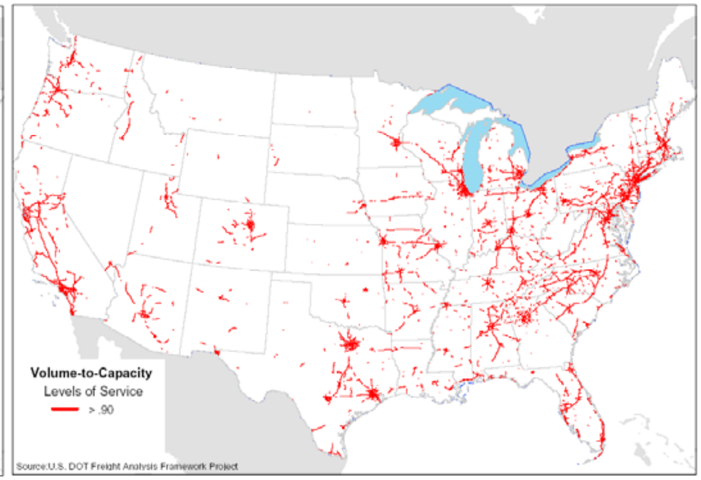


Figure 4. Projected Congested Highways 2020

Source: U.S. DOT Freight Analysis Framework Project

The crisis of the demand/capacity imbalance affects the daily lives of citizens as well as almost every sector of economic activity. Commutes to work are time-consuming and aggravating. Non-work trips must also be planned at particular hours in order to avoid congestion or with extra time allotted to allow for the lack of reliability in travel times. Freight shipments become costly and unreliable. Air pollution is exacerbated by cars and trucks stuck in traffic. Even rural areas that have never seen traffic jams are affected when highway congestion on urban roadways blocks their agricultural products from reaching ports and customers.

Localities across the country are struggling with this crisis and are responding with a variety of strategies. A few communities are actively expanding or extending major highway corridors. In some locations, new investment is being directed to transit systems that seek to provide alternative options to the personal automobile. Other communities are pursuing "spot investment" strategies attempting to deliver projects to help traffic on less than a "corridor length" scale. There is also an emerging interest in the *operations* of existing facilities in order to assure that they deliver transportation benefits with the greatest possible efficiency.

Almost everywhere, the planning for expansion of transportation facilities is linked to local discussions and often controversy over the patterns of land use and land

[5] WSDOT has offered important critiques of TTI's methodology that relate to detailed city-by-city comparisons found in past TTI reports. WSDOT has been collaborating with TTI and others in extensive efforts to improve the analysis and reporting of traffic congestion across the country. None of the issues in these efforts take away from the clear overall conclusions reached by TTI as the growing crisis of urban traffic congestion and delay.

development that result from and affect citizen’s choices about how society organizes individual and community life in relation to space.

The following sections of this paper present background information on congestion, the ways in which bottlenecks and chokepoints affect system efficiency and strategies for addressing bottlenecks and chokepoints. This paper also presents potential policy options for future bottleneck and chokepoint investments and provides examples across the state.

Background: Mounting Congestion and Delay

Delay on Washington's state highways is calculated by the Washington State Department of Transportation (WSDOT) through a variety of direct observations (from highway embedded induction loops that act as sensors measuring volume and speed, for example) and careful estimates. Figure 5 presents a picture of the average hours of delay per day likely to be tallied for a given segment of highway. The higher the spike, the greater the delay. The highest spike depicted on the map in Figure 5 is located at the interchange for I-5 and I-90 in Seattle, where the average tally is about 825 vehicle hours of delay per lane mile per day. Figure 5 illustrates that the greatest delay on the state highway system is found in the Central Puget Sound area. Significant delay is also seen in the Tri-Cities, Vancouver and Spokane with much smaller magnitudes of delay is scattered throughout several other areas of the state. Figure 5 does *not* present a picture of delay on city or county streets or highways, a factor that would undoubtedly change the appearance of the map.

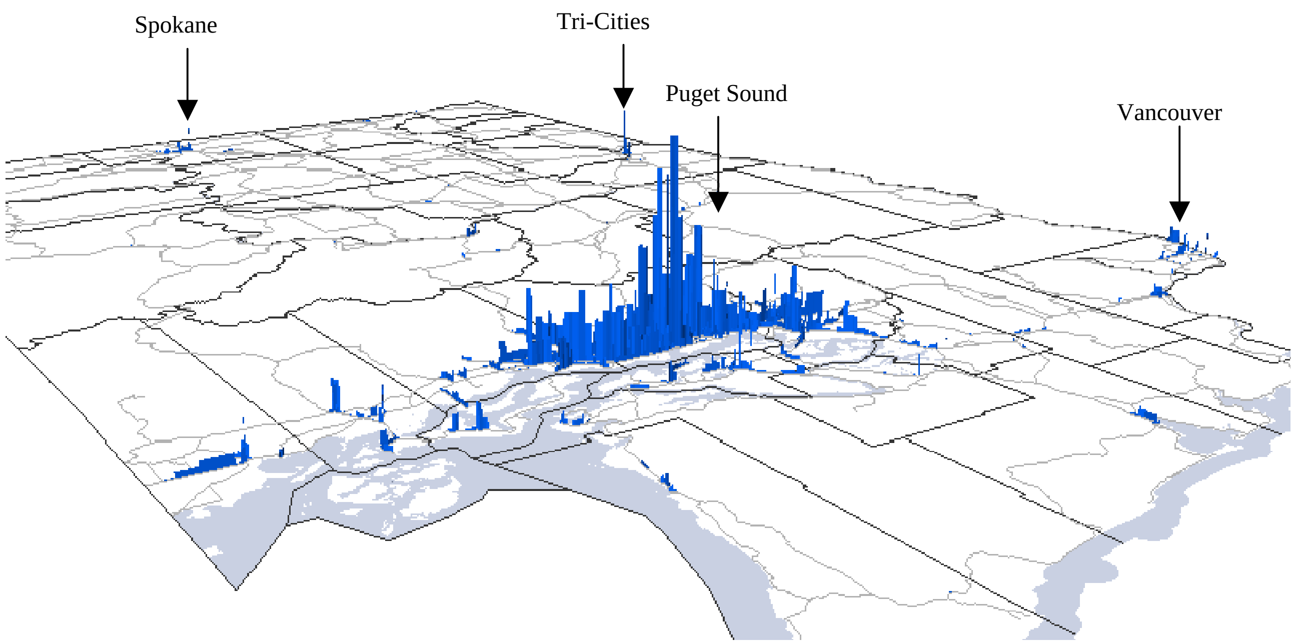


Figure 5. Total Daily Vehicle Hours of Delay Per Lane Mile across the State of Washington[6]

Source: WSDOT

[6] Figure 5 shows total delay on a typical weekday by highway segments. It is based on the idea that a highway will have a "spike" for delay if there is congestion. The higher the delay, the higher the spike. The highest spike on the map is for Interstate 5 at I-90 and it shows over 825 hours of delay per lane mile per day.

Delays for highway traffic are expensive. WSDOT performs a calculation of the cost of traffic delay using a number of assumptions to assist in assigning dollar values to particular delay circumstances.[7] Using these assumptions, a rough calculation of the annual social cost of the delay generally depicted in Figure 5 is on the order of $1.6 billion per year.[8]

Highways with large amounts of delay are concentrated in the Puget Sound Region including I-5, I-405, SR-520 and SR-167. These areas of delay are in the major urban centers in the region including Seattle, Tacoma, Bellevue, and the major employment sites in the Green River Valley and the Overlake area in Redmond. The largest amount of delay is located in the I-5 corridor approaching downtown Seattle. The map in Figure 6 illustrates hours of delay in more detail for the Puget Sound Region freeways and expressways; the taller bars represent higher levels of delay.

Measuring Congestion

Measuring congestion on highways and other transportation facilities is a complicated task. WSDOT is an active participant on the national level in these areas, contributing data from its extensive network of traffic sensors and monitoring equipment as well as theoretical insights from its own analysis and those of its consultants, including the Washington State Transportation Center (TRAC). Some of this work relates directly to managing traffic operations and WSDOT's large commitment to traveler information systems. Other purposes of the work include planning and modeling potential system investments. Summaries of WSDOT's efforts and contributions in congestion measurement can be found online at:

http://www.nawgits.com/icdn/wsdot_measures.html and http://www.wsdot.wa.gov/pugetsoundtraffic/traveltimes/.

This paper does not deal with the entire body of WSDOT's information and insights on the scale and nature of congestion in Washington State. Instead, this paper focuses on a single and simple manifestation of congestion; namely, **delay**. Delay, in WSDOT's view, is the most basic and accessible measure for the scale of the problem created by the capacity/demand imbalance.

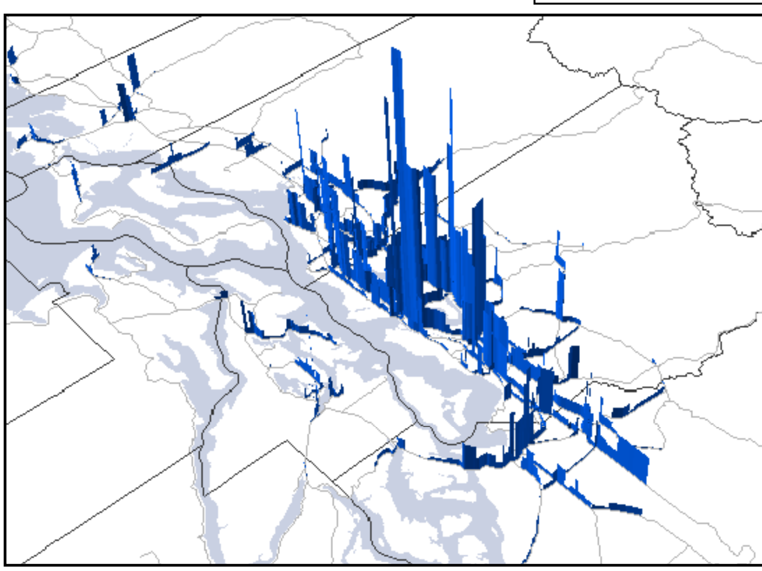


Figure 6. Existing Hours of Delay Per Lane Mile Per Day on Puget Sound Freeways and Expressways

Source: WSDOT

[7] The methodology is described in more detail in Appendix 1.
[8] This compares to $800 million dollars invested in State Highways in 2001.

Demand/Capacity Imbalance Growth

Population and jobs are expected to continue to grow in Washington State. As shown in Figure 7, the statewide population is expected to increase by 2.3 million (from just 5.9 million in 2000 to approximately 8.2 million in 2030). Most of this growth is projected to occur in the state's Metropolitan Statistical Areas (MSA).[9]

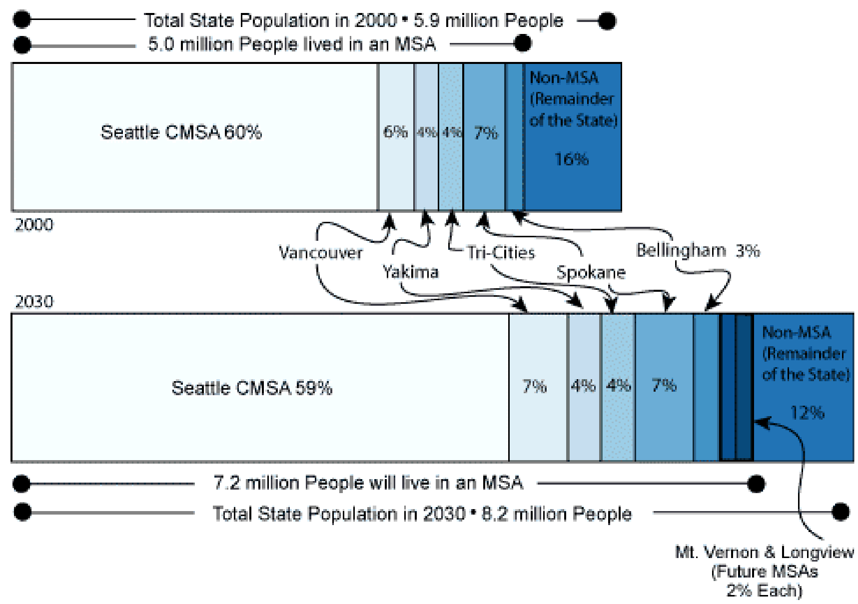


Figure 7. Statewide Population Growth Trends

Source: Data, Office of Financial Management (OFM). Graphic, WSDOT Data Library <http://edit.wsdot.wa.gov/planning/wtp/datalibrary/population/PopulationGrowthMetropolitan.htm>

This population growth will translate into substantial increases in travel demand. This growth is illustrated by the projected changes in Vehicle Miles Traveled (VMT) shown in Figure 8. Consequently, the gap between demand and capacity will grow wider in the future, especially in the three major urban areas and several of the larger cities in the state.

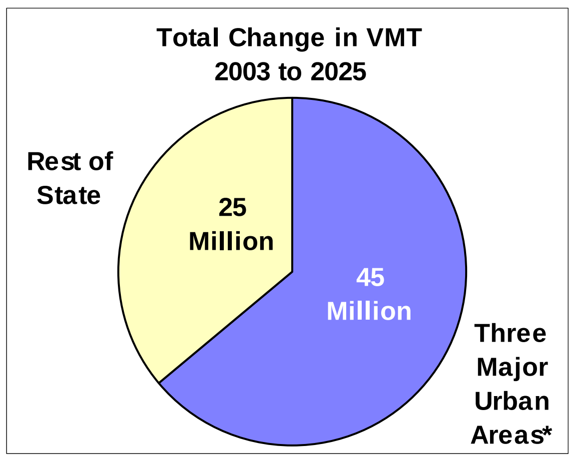


Figure 8. Estimated VMT Growth in the State and Three Major Urban Areas*

Sources: WSDOT, PSRC, SRTC and RTC
*Puget Sound Region, Spokane County and Clark County

Freight shipments throughout the state will continue to grow as well. According to the Federal Highway Administrations (FHWA) Office of Freight Management and Operations in 1998 shipments to, from, and within Washington State totaled 466 million metric tons valued at $353 billion. By 2020, the projection is that this volume will grow to 834 million metric tons valued at $1,167 billion.

[9] The general concept of a H**Metropolitan Statistical Area**H (MSA) is a U.S. Census Bureau-defined urbanized area of at least 50,000 inhabitants with a total metropolitan population of at least 100,000. Additional contiguous counties are included in the MSA if they meet certain requirements of commuting to the central counties and other selected requirements of metropolitan character (such as population density and percent urban). A metropolitan statistical area identified as a Consolidated Metropolitan Statistical Area (CMSA) has a population of one million or more and also has separate component areas (PMSAs - primary metropolitan statistical areas) meeting statistical criteria and supported by local opinion.

The costs and burdens of traffic congestion affect various sectors in different ways. For example, individual travelers and commuters often accommodate traffic and congestion by shifting travel routes and schedules. Although the costs of lost time and slowdowns may be large in total, individuals may see these costs as acceptable trade-offs for housing or job location choices, the opportunity to see a major sporting or entertainment event, and visiting friends. For shippers, who must share the roads, rails and airports with personal travelers, being "stuck in traffic" has a more direct economic impact to the health of a business and the State's economy.[10] Distributors, such as FedEx, cannot change travel routes and schedules, which are a function of customer needs.

The Implication of Delay

There is a second side to delay that compounds its negative impact on system performance: lost efficiency. Traffic engineers and planners armed with tools (like real time induction loops embedded in the pavement) can collect data and closely examine patterns of volume and speed of vehicles on a roadway. That information allows insights into the efficiencies of highways in performing their purpose of moving people and goods.

One of these insights, proven by an extensive body of research and investigation around the country, is that the highest volumes of traffic on a freeway are generally not associated with the highest speeds. At higher speeds, drivers tend to increase vehicle spacing allowing fewer vehicles to pass a given point of the roadway in a given period of time. An "optimal" speed characterized by drivers' comfort with somewhat closer vehicle spacing would allow an "optimal" number of vehicles to pass through.

The optimal speed from the standpoint of vehicle throughput[11] efficiency can be generally examined for a segment of I-405 at 24th Northeast from Figure 9. It plots the volume throughput (the higher volumes are to the right and can be read on the x-axis) against speed (the higher speeds are to the top and can be read on the y-axis), based on data collected from dozens of snapshots of

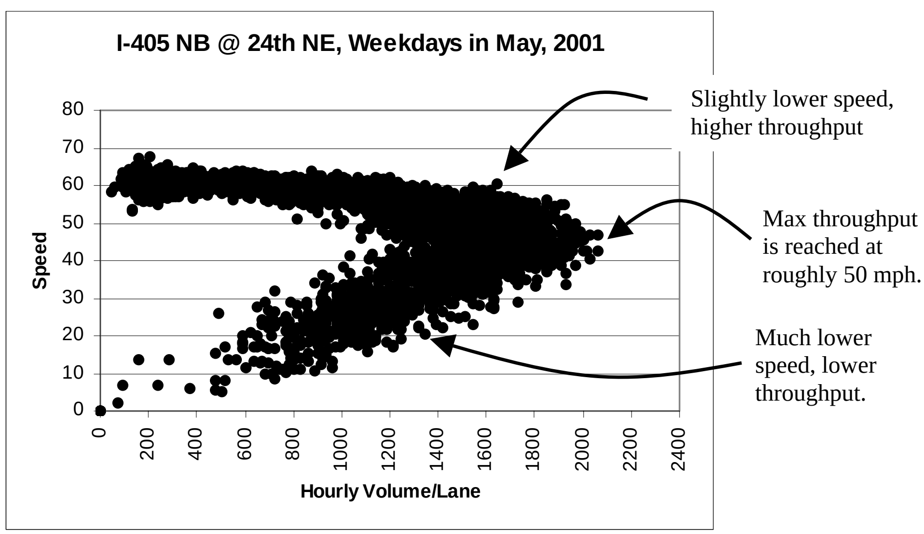


Figure 9. Speed and Throughput Relationship
Source: WSDOT Loop Detector Data

[10] See Washington Transportation Plan Freight Systems Paper.
[11] The number of vehicles passing a single point in a given period of time.

performance taken during the month of May 2001. The figure demonstrates that the highest throughput—just slightly in excess of 2000 vehicles per lane per hour—was attained when highway speeds were operating between forty and fifty miles per hour.

As delay mounts, speeds drop; this is because as the roads become cluttered with vehicles, drivers tend to react to the conditions in many ways. Some drivers become more cautious and increase their vehicle spacing while others react by becoming more aggressive and maneuvering back and forth between the lanes in an effort to advance their position relative to the cars around them. In addition, truck drivers are trained to keep a safe following distance from cars; when cars cut in front of them they must slow to make more space. As conditions develop in this way, the *efficiency* of the highway, the number of vehicles passing the counting point in a given period of time, drops dramatically. For example, on I-405 when congestion causes a reduction in speed, the throughput for falls to a range between 700 and 1700 vehicles per hour (the mean at the low of 30 mph was about 1200 per hour). This is less than 60% of the mean throughput at 47 mph.

The loss of *efficiency* on I-405 can be seen more clearly in Figure 10. On northbound I-405 at NE 24th Street nearly half of the capacity was lost around 8:00 AM due to congestion as shown in Figure 10. In other words, less than 1 lane of capacity (out of 2 general purpose lanes) was available at a time that it is needed the most.

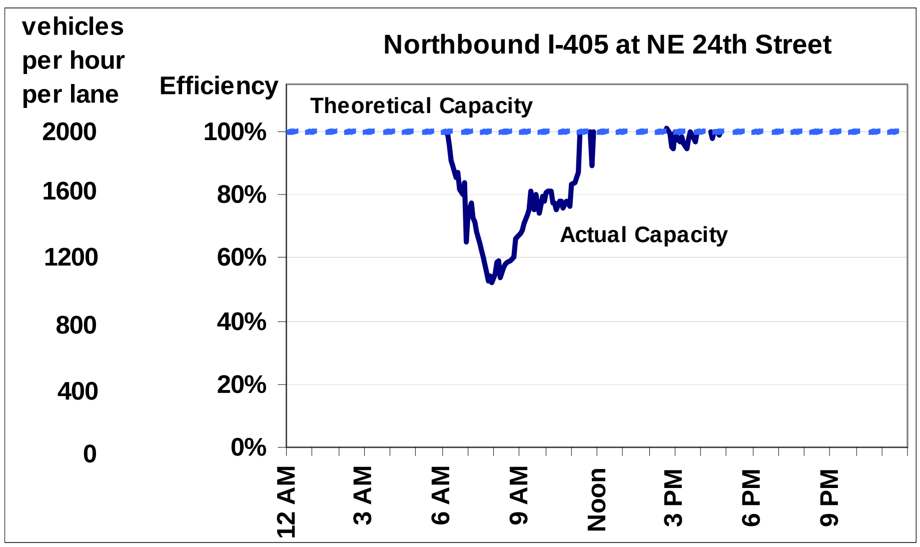


Figure 10. Productivity Lost Due to Delay
Source: WSDOT Loop Detector Data

Delay induced system productivity loss is not limited to I-405. Figure 11 depicts the percentage of general-purpose lane capacity/productivity lost during the heaviest travel time period in the worst direction of travel on Puget Sound freeways where loop data is available.

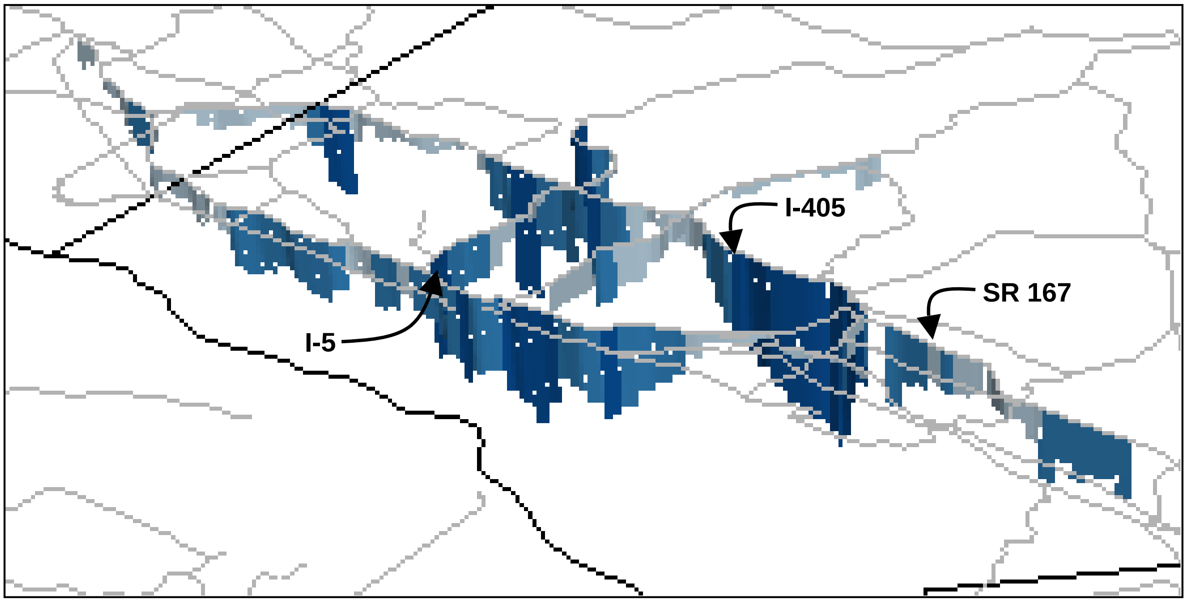


Figure 11. Percentage of Central Puget Sound Freeway Productivity Lost Due to Delay
Source: TRAC using WSDOT Loop Director Data

As discussed previously, the heaviest loss in the system occurs on I-405 northbound just north of SR-900, reducing the efficiency by nearly half. A similar situation occurs on I-5 northbound through Seattle and I-405 southbound near the King/Snohomish County line.

What are the implications of the optimal throughput curves, like I-405 depicted in Figure 9, for determining the goals and strategies for investment in highway capacity?

Highway engineers have long known the shape of Figure 9. Its exact form however, varies considerably from time to time and place to place. Up until a couple of decades ago, the maximum throughput for many highway systems was observed in the 35 to 45 mph range. As time has passed and drivers have become more accustomed to driving in congested conditions, drivers tend to maintain relatively tight spacing at higher speeds that used to cause drivers to spread out. That is why, today, the maximum throughputs on many congested highways, like on the segment of I-405 illustrated in Figure 9, are now associated with speeds as high as almost 50 miles per hour. In the Los Angeles area, drivers seem to be taking higher speeds and closer spacing to a level not yet seen in this area—is it a harbinger of things to come? Will speeds associated with optimal throughput continue to climb higher, and if so, to what limit?

The virtues of economic efficiency for the users of the highway as a whole may be lost on individual drivers. Moving along in traffic at 50 miles per hour, some drivers feel they are still suffering "delay" from congestion relative to the posted speed limit, which is typically 60 miles per hour in urban areas. Nevertheless, the intuitive necessity of maintaining throughput is why drivers and highway operators alike respond so positively to incident response programs and other management techniques that assist with keeping traffic moving. Two broad strategies to which Washington State has been heavily committed in this quest for efficiency of throughput are the use of ramp metering and the commitment to HOV lanes. HOV lanes provide travel time and reliability premiums to travelers who can shift away from single occupancy vehicle roadway use patterns.

The throughput curves lend powerful support to the contention that dynamic roadway pricing could make major contributions to the efficiency of our existing highways and freeways. These dynamic pricing systems are designed to maintain the volume/speed balance at its optimal position for efficiency of throughput. This system of High Occupancy Toll (HOT) lanes that use dynamic pricing would provide a benefit to all taxpayers – whether they use the tolled lane or not!

Addressing the Demand Capacity Imbalance

For decades, the State has planned for, and with limited funding, made investments in our transportation system. For the most part, these capital investments have been targeted on strategic general capacity improvements; high occupancy vehicle lanes and enhancements to maintain the maximum throughput of a facility like ramp metering and signal synchronization. In many of these areas, Washington State has been a national leader and it is clear that we must continue to make further investments in these areas. It is also clear that while we build on our successes, we must continue to look at new and innovative ways to address this growing demand.

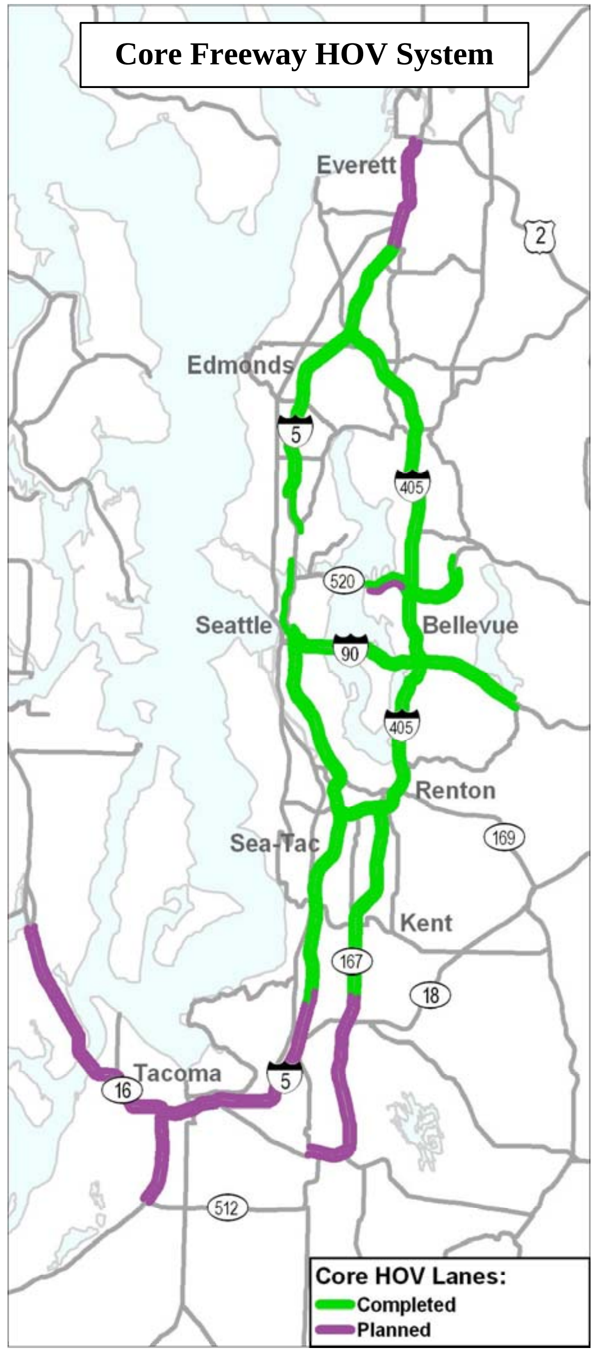


Figure 12. Core HOV System
Source: WSDOT

The High Occupancy Vehicle (HOV) Lane System

More than twenty years ago WSDOT began planning and constructing a system of freeway High Occupancy Vehicle (HOV) lanes. WSDOT's efforts resulted in the creation of HOV lanes throughout the Puget Sound Region, totaling over 205 lane miles with another 92 lane miles planned, as shown in Figure 12. A freeway HOV lane has also been implemented on I-5 in Clark County approaching the Columbia River Bridge.

These HOV lanes, which cost over a billion dollars to build and constitute the majority of WSDOT's new construction program in the 1990's, dramatically increased the person throughput[12] of the freeway system in the state's most congested urban corridors.

[12] The number of people passing a single point in a given period of time.

The HOV system also provides a benefit in alleviating chokepoints and bottlenecks. Their free-flowing lanes allow HOV's to bypass many of the chokepoints and bottlenecks of the general purpose lanes while providing an attractive option to driving alone. The HOV lanes provide a travel time savings benefit over their corresponding general purpose lanes throughout the Puget Sound Region as shown in Figure 13.

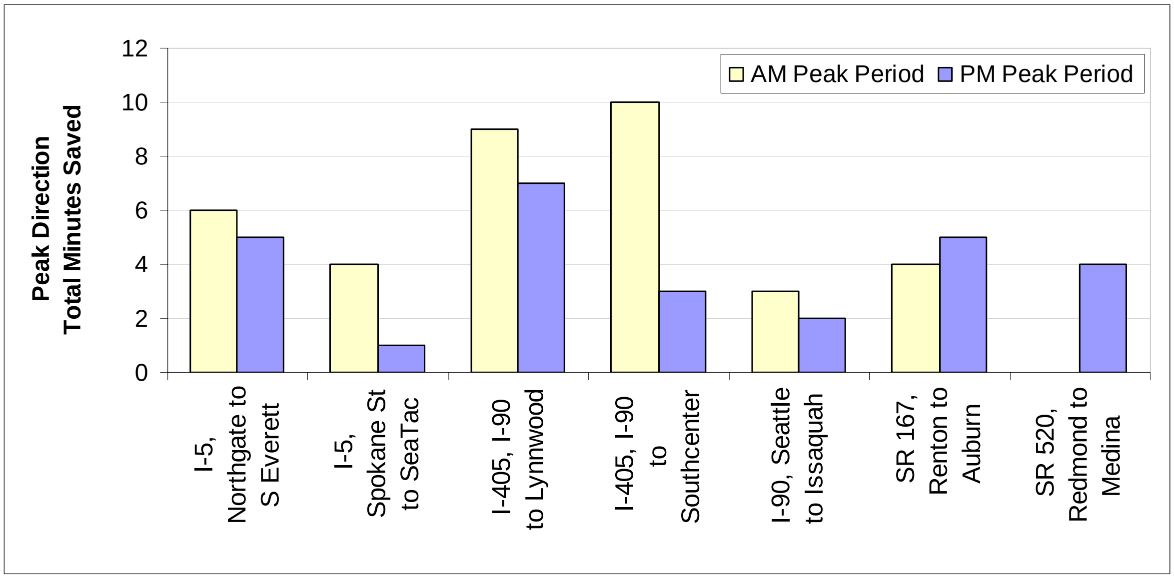


Figure 13. 2002 Peak Period Travel Time Savings
Source: WSDOT

As HOV system use grows, the lanes themselves are beginning to develop their own bottlenecks and chokepoints. Several of these include the end points of the HOV lanes; some of these bottlenecks and chokepoints have been eliminated through the extension of the HOV lanes. A prime example of this was the 2002 extension of the southbound I-5 HOV lane to Federal Way. The general-purpose congestion that had been a daily occurrence during the PM peak period on the Southcenter Hill largely disappeared, reducing delay in both the general purpose and HOV lanes as shown in Figure 14.

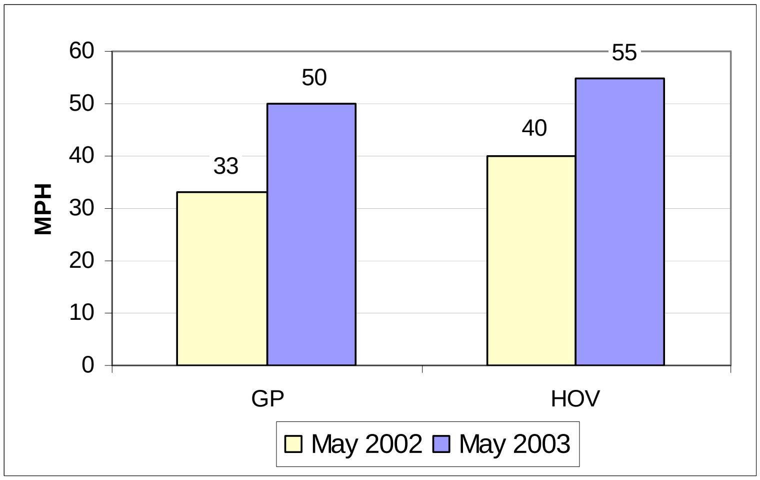


Figure 14. Average PM Peak Period Speeds on SB I-5 at S 184th ST before and after HOV Lane Extension

Source: WSDOT

Additional investments contribute to the system's efficiency; an example is the direct access ramps, funded largely by Sound Transit, that allow buses to access the HOV lanes without weaving across general purpose lanes. During the peak hours this weaving can result in traffic slowdowns as far as a mile upstream. Other investments and actions, by WSDOT and other entities, also contribute to the HOV system's effectiveness.[13]

HOV lanes, like general purpose lanes, experience their maximum throughput when the speeds are 40 to 50 mph and volumes are near 2,000 vehicles per lane per hour. To prevent the breakdown of the HOV system, performance goals call for the freeway HOV lanes to maintain an average speed of 45 mph or greater at least 90% of the time during the peak hour for six consecutive months.

In the fourth quarter of 2002, four out of fourteen corridors did not meet the performance goal, however, closer examination of the data shows that poor performance is concentrated in just a handful of locations along the 205-mile system. Although the HOV system operates largely independent of bottlenecks and chokepoints on the general purpose lanes, there are places where the HOV lanes and general purpose lanes both suffer from congestion. This is especially true where the HOV lanes terminate, such as on northbound I-5 approaching downtown Seattle, and on I-5 at Northgate. Completion of the HOV system extensions can alleviate congestion at some of these chokepoints, and improve both HOV and general purpose lane performance.

The last two decades have given WSDOT a wealth of experience in planning and implementing the HOV system. Ongoing monitoring of HOV system performance confirms the success of the system. Trends in HOV system use, along with population and employment trends in the state's largest urban areas, lead to important conclusions about how the HOV system will need to be managed in the future:

- The HOV system is presently functioning as intended, providing a travel time savings incentive to HOV's.
- As demand grows there may be a need to revisit HOV operating policy to ensure efficient performance is maintained.
- Completion of the adopted core HOV system plan will help alleviate congestion in both general purpose and HOV lanes.

It may be possible to make more efficient use of surplus HOV system capacity by conversion to HOT lanes[14].

[13] Express bus service using the HOV lanes provides an incentive to shift from commuting via single-occupant vehicle to transit. Transportation Demand Management (TDM) programs also provide incentives to make use of HOV modes (TDM will be discussed in greater detail in another paper). Arterial HOV lanes provide priority to transit on local streets allowing them to avoid many chokepoints. These are a complement to the freeway HOV lanes constructed by WSDOT.

[14] A strategy that has promise for simultaneously making more efficient use of surplus HOV lane capacity and alleviating GP lane congestion is conversion of HOV lanes to High Occupancy Toll (HOT) lanes. HOT lanes allow single occupant vehicles to use the HOV lanes by paying a toll. Adjustments are constantly made to the toll based on traffic levels; when demand is high, the toll is increased to prevent the HOT lane from becoming congested. This strategy, which has been implemented successfully in Texas and California, makes the most efficient use of available capacity and preserves the speed and reliability advantage for transit and HOV traffic. Where demand vastly exceeds system capacity this only reduces bottleneck congestion by taking advantage of surplus HOV lane capacity.

Ramp Metering

A ramp metering system is a set of physical investments (signals and loop detectors) at specific freeway on-ramp locations combined with technological infrastructure investments in hardware and software to make the system work more efficiently. Ramp metering consists of a series of detector loops embedded in the freeway lanes that sense the delay build-up by measuring the space between vehicles. When it detects the spacing reaching a preset threshold before flow breaks down, it turns on the ramp meter signal to regulate/reduce the inflow of vehicles at on ramps to keep the traffic flowing at or near its peak levels on mainline freeway lanes. Ramp metering, in effect, contributes to system efficiency by maintaining the freeway as close to maximum throughput as possible.

The effect of ramp metering in reducing delay is well documented. The graphs in Figure 15 and Figure 16 show before (July 25, 2001) and after (Sept. 6, 2001) comparisons of ramp metering on SR 520 between I-5 and the floating bridge on a typical morning. The black/darkest shading shows stop-and-go traffic conditions. Prior to ramp metering, stop-and-go conditions started to occur around 7:25 am and continued to about 9:25. After the Ramp metering, most of the stop-and-go condition was eliminated.

SR 520 Eastbound Morning Congestion I-5 to Lake Washington Blvd

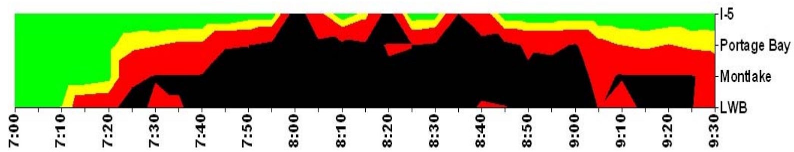


Figure 15. SR-520 Before Ramp Metering (Wednesday July 25, 2001)

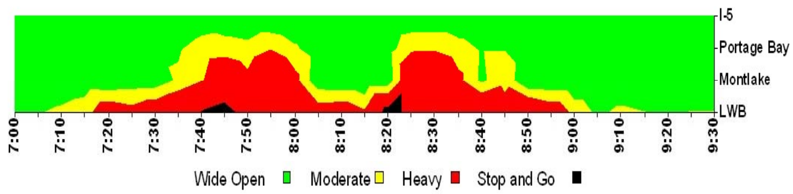


Figure 16. SR-520 After Ramp Metering (Thursday September 6, 2001)

Source: WSDOT

Although ramp metering is highly effective in improving system efficiency it can cause problems when trucks are unable to reach mainline speeds coming from the ramp because of a steep grade or insufficient ramp length. The implementation of ramp metering in areas with a large amount of freight movement should include geometric ramp design considerations for trucks.

Traffic Signal Synchronization

Unsynchronized traffic signals are an issue that most drivers and passengers can relate to. It is that annoying situation of seeming to stop at every light or to wait three short lights to get through an intersection and it always seems to happen at a time when you are in hurry. Although it seems like one of the most fixable bottleneck and chokepoint problems, it is more complex than it appears.

At signalized intersections, green times (the length of time a signal is green) are assigned to specific movements based on the movement’s demand at certain time intervals. A surface arterial corridor in urban areas has signalized intersections every few blocks. Signal synchronization's main objective is to coordinate green time for through movements so that most of the through traffic can continue to arrive on "green" at progressive intersections, thereby reducing stop-and-go conditions from intersection to intersection. Like ramp metering for freeways, signal synchronization contributes to arterial operation efficiency similar to the maximum throughput concept on freeways.

According to the Texas Transportation Institute (TTI), this is a strategy with big-time payoffs. It is also a strategy that has counterpart dividends for cities and counties because virtually all locally owned roadways are surface streets.

The following example, illustrated in Figure 17, documents the effectiveness of signal synchronization along the 1.35 mile SR 527 corridor from 228th Street SE at the south end, to SR 524 at the north end.

Implementing signal synchronization showed a reduction in average vehicle travel times between 16 seconds (northbound AM peak period) and 2 minutes 27 seconds (northbound PM peak period). This remarkable reduction in travel times can be more fully appreciated when expressed in terms of percent reduction of travel time. The reduction in travel time for the peak hour directional traffic flow is 41% for the southbound morning commute, and 38% for the northbound evening commute.

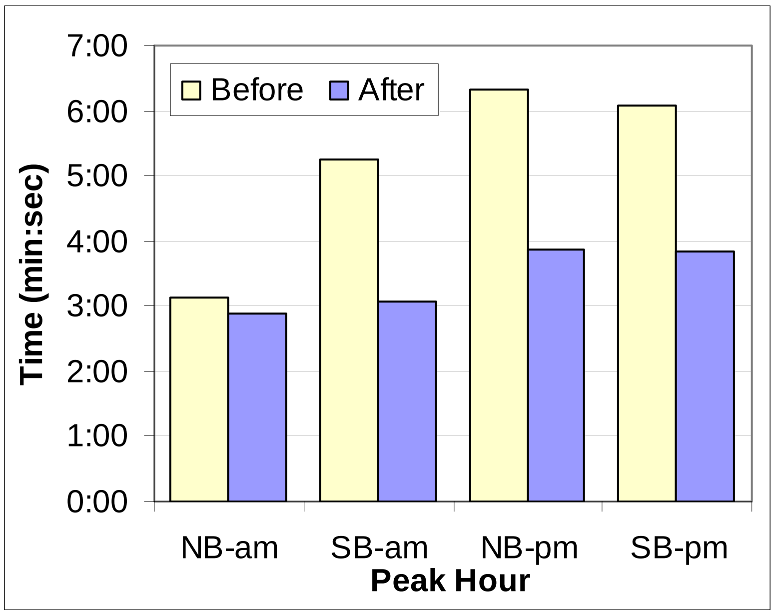


Figure 17. Signal Optimization Results for SR 527

Source: SR 527 Study Corridor from 228th Street SE at the south end, to SR 524 at the north end, *"City of Bothell, Traffic Signal System Optimization, Phase I,"* 2002.

Programs for Addressing Bottlenecks and Chokepoints

As illustrated in this paper, Washington State has and will continue to make capital investments, consistent with funding availability, in the transportation system. We are doing a lot of things right and we must continue to advance the programs we have started. However, we have been falling behind in transportation system growth relative to the growth in population, jobs, and travel that have occurred in our state.

Major corridor improvement plans for some of our most congested corridors have been developed. Several proposed multi-billion dollar solutions to expand corridor capacity, include adding two lanes in each direction on I-405; completing the North/South Freeway in Spokane; completing missing freeway links such as SR 167 from the Port of Tacoma to Puyallup and connecting SR 509 south of Sea-Tac Airport to I-5; and two notable preservation projects that add additional capacity, replacing the I-5 Columbia River Bridge with a wider span between Vancouver/Portland and replacing/widening the SR 520 Evergreen Point Floating Bridge.

At the same time that these corridor plans were being developed, funding to implement these plans was getting harder to come by. A nickel gas tax increase in 1990/91 provided nowhere near the revenue needed to fund multi-billion dollar projects, and by the late 1990s much of the real buying power of that increase was lost to inflation and a growing need for system preservation funding. A proposed public/private initiative program that would have solicited private sector investment in these large-scale projects was largely rejected by the public and the Legislature (the one remaining project from that proposal, the new Tacoma Narrows Bridge, is proceeding as a publicly funded toll bridge)[15]. Federal funding has remained steady for the past several years, and hopes of an increase that could fund large corridor capacity projects are fading as Congress struggles with a growing federal deficit, high gas prices, and resistance to a federal gas tax increase.

In 2002, the Washington State Legislature authorized the Puget Sound Region to establish a Regional Transportation Investment District (RTID) with up to $20 billion of taxing authority to fund these large-scale projects. Since RTID requires voter approval, and polls have indicated voter concern over the sources and magnitude of taxes to fund these projects, RTID has been delayed. This history suggests that, although large-scale corridor improvement plans are desirable as a long-range vision, funding reality says that we need smaller scale and more affordable capital investments targeting specific traffic restrictions such as bottlenecks and chokepoints.

The Legislature's 2003 Transportation Funding Package is a good lesson in the targeted investment approach. For example, the package provides $485 million for targeted improvements to I-405 at the worst congested locations: the Kirkland Crawl, through the Wilburton Tunnel approaching I-90 southbound, and at the I-405/SR 167 Interchange

[15] In 1993 the Washington State Legislature approved the New Partners: Public Private Initiatives in Transportation Program allowing the WSDOT to solicit and select six private sector transportation project proposals. The original six selected were Park and Ride capacity enhancement, SR-18 improvements, SR-522 improvements, congestion pricing of HOV lanes, Tacoma Narrows Bridge expansion and SR-520 Bridge improvements.

vicinity. Similarly, the package targets funding at other locations where traffic flow improvements can make a difference.

The recently completed I-405/SR 167 Flyover ramp is a good example of one such targeted investment. The I-405/SR 167 Ramp Separation project completed in 2003 focused directly on a bottleneck. Figures 18 and 19 show the before and after analyses on average weekdays and weekends respectively.

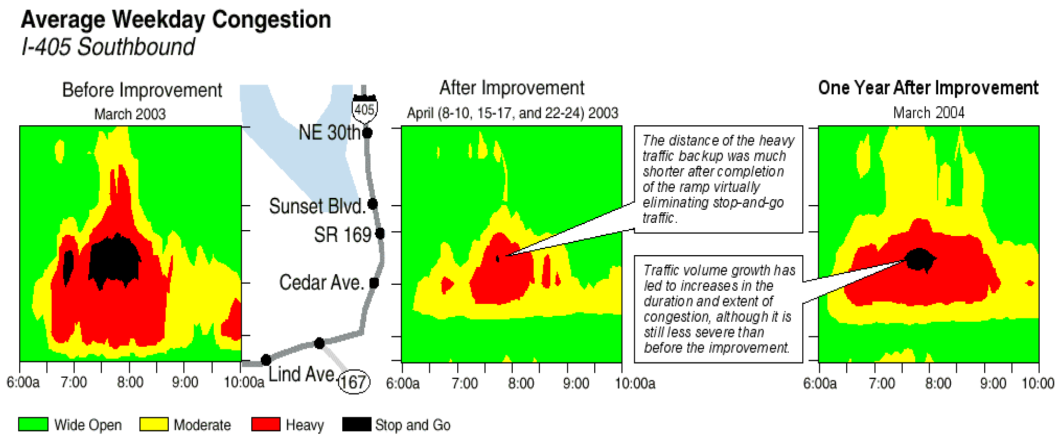


Figure 18. Weekday I-405 and SR-167 Flyover Improvement

Source: WSDOT

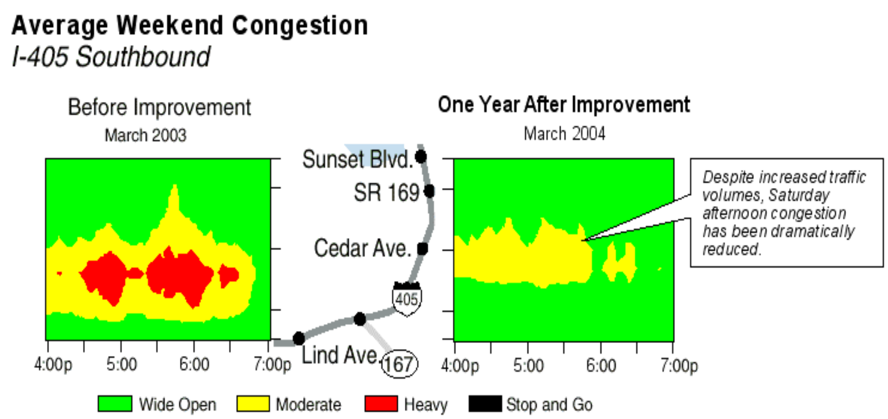


Figure 19. Weekend I-405 and SR-167 Flyover Improvement

Source: WSDOT

The dark color indicates stop-and-go condition. The red (or dark gray in black & white) shows heavy congestion where the speed is below 45 miles/hour. On weekdays prior to the opening of the new ramp, stop-and-go conditions started to occur as early as 6:45 am, then reoccur at 7:15 am and continue well after 8:00 am. Immediately after the opening of the new ramp, the stop-and-go condition was almost entirely eliminated. In the past year we have seen continued growth in the I-405 mainline volumes as well as the I-405 southbound to SR 167 southbound ramp. The daytime volumes have grown 3.6% and 5.3%, respectively, comparing April 2003 to March 2004. Despite serving higher volumes, the congestion at the interchange area is still considerably lower than the conditions prior to the project. On weekends, both the stop and go traffic and heavy congestion conditions have been entirely eliminated.

Although a more detailed before and after study has yet to be conducted, pending more data, a preliminary analysis showed that the ramp would eliminate 400 vehicle-hours of delay on a typical weekday: a user benefit of $2 million per year. With the estimated additional safety benefits of $470,000 per year, the investment will pay for itself in approximately four years, a relatively quick recovery when compared to other comparable large-scale corridor improvements that typically take 10 or more years to recover their investments.

Building off of this successful example, this paper recommends an interim set of improvements to what we have termed bottlenecks and chokepoints. These enhancements are smaller scale capital investments that cost less than full corridor expansions, target the worst locations and seek to return the highest benefit for the amount invested. Typically, these projects can be implemented more quickly than full corridor solutions, and they often remove a restriction that allows the existing roadway's full capacity to be utilized, thereby increasing efficiency. These Bottleneck and Chokepoint improvements, when coupled with operational efficiencies[16], will allow real flow improvements to be made to the transportation system in the short term at a smaller cost than the full corridor build-out proposals. The paper on Building Future Visions reflects the ultimate need to make large scale corridor improvements to accommodate Washington's long range growth, but recognizes that these improvements are likely beyond the near term future.

[16] See System Efficiencies Issue Paper for more information.

Bottleneck and Chokepoint Investment Opportunities

Given the limited funding currently projected for Washington State's transportation needs, a strategy that targets bottlenecks and chokepoints must be considered as a short- to mid-range strategy. This approach will allow the state to, given the current economic and tax climate, make targeted investments that can continue to move the state forward on transportation issues. While this is a logical strategy, there are many ways to look at how this might be approached. When funding for transportation is tight and demand is growing, everyone's projects are a high priority when looked at from their location and viewpoint. This is where the policy discussion begins.

There is a wide range of policy objectives and trade-offs that can be made to allocate the funding available for bottlenecks and chokepoints. The following policy options and example projects were developed to initiate the needed debate on this topic. These policy options and example projects are not intended to be comprehensive or overly detailed, but to provide the Transportation Commission, Legislature and the citizens of the State a starting point for discussion. Basic policy objectives for addressing delay through a bottleneck and chokepoint project might include:

Commuters

The unreliable travel times associated with congestion make getting to work a frustrating experience. The extra time we must allow for, robs us of valuable time with our families and other important activities. In the state's urban areas this commute can be accomplished in two major ways, either driving alone or utilizing alternative options such as carpools, vanpools and transit. The solutions to removing bottlenecks and chokepoints for these two options will be slightly different but often overlap or provide benefits for all commuters.

At times, even with the best transit access we may have to drive alone to work. While we are stuck in traffic, we can sometimes identify a small project that would reduce delay and improve our travel time. These include projects that could be completed quickly to improve a

Example Projects

Spokane Vicinity - I-90 – Argonne Road to the east – improve by adding lane capacity in stages. This is a heavily used commuting corridor from the residential areas east of Spokane into the Spokane urban center.

SR 28/SR 285 – Approaches to George Sellars Bridge – improve connections at the approaches to this bridge, which is located at the south end of the city. This is one of the major problem locations in the Wenatchee urban area. Many commuters use this bridge to travel from Wenatchee to East Wenatchee resulting in congestion each day during peak periods.

SR 167 – Puyallup to Auburn – complete HOV lanes – SR 167 has become one of the most congested corridors in the Central Puget Sound region due to residential growth in south King and north Pierce Counties. This congested highway would greatly benefit from completing the HOV lanes south to Puyallup.

merge or reduce weaving like the infamous Mercer weave on I-5, or add a left turn lane to avoid stacking up vehicles behind the left turning vehicle.

For the transit, carpool or vanpool users, the projects can be different. They could include such projects as a bypass lane at a ramp and figuring out how to allow transit to safely use shoulders during the peak all the way up to more expensive projects like direct access ramps for transit and carpools. These types of projects would be developed to give people commuting to work ways of avoiding congestion while at the same time taking vehicles off the road and improving conditions for all users.

Freight[17]

Freight movement on our transportation system is critical to our region and to the nation. The ability of freight to move efficiently throughout the state and with minimal delay affects the cost of goods and the retention and growth of jobs. Distributors state that there is no alternative to Washington's major highway system, and use I-5, SR 167 and I-405 as primary routes. Significant congestion is found on I-5 from Everett to Olympia, and the full length of I-405 and SR 167.

If we were to look at reducing delay, the project list could overlap with the commuting needs projects. Projects on this list would include improved connections to the ports and regional distribution centers such as grade separations at rail crossings, all weather improvements to ensure all year travel reliability, including avalanche protection in mountain passes. Projects targeting freight movement would also include truck holding/storage areas (an example is the widened shoulder on I-90 near Snoqualmie Pass) and truck climbing lanes that would improve travel and safety for all travelers by reducing vehicle/truck conflicts.

Example Projects

I-5 in the Chehalis Vicinity – Add lanes to I-5 – phased approach – I-5 carries more freight traffic than any other highway in the state. In the Chehalis vicinity I-5 is reduced to two lanes in each direction. This results in delay for freight movement.

SR 509 at Port of Tacoma – Improve connection into the Port – Phase 1 of the SR 509 development plan was implemented several years ago by constructing a new bridge and highway connection from I-705 to the vicinity of the Port of Tacoma Road. Phase 2 adds two more interchanges connecting SR 509 to roadways leading directly into the Port facilities.

I-90 at Snoqualmie Pass – Provide avalanche protection – I-90 carries the second highest tonnage of freight in the state. Several times each winter it must be closed due to severe avalanche danger. Closures cause scheduling nightmares, cost trucking-dependent companies up to $100 per hour in labor and fuel alone, and stop eastern Washington's food products from getting to Central Puget Sound customers.

[17] See Washington Transportation Plan Freight Systems Paper.

Interregional movement

Much of the state's transportation system was built to allow people to travel relatively short distances. However, the Interstate System was originally built to accommodate long distance trips and the movement of troops across the country. If projects were chosen to accommodate long distance trips, the project list would include passing and truck climbing lanes in key locations and improved lane continuity in areas such as downtown Seattle. Again many of these improvements would benefit general travel and reduce delay on our highways.

Example Projects

SR 97 – Blewett Pass – Additional passing lanes – The Blewett Pass portion of SR 97 is one of the major routes connecting south central Washington with north central Washington. While there are some passing lanes currently in place, additional passing lanes would be beneficial.

SR 97 – Satus Pass – Additional passing/truck climbing lanes – SR 97 traverses the state from the Canadian Border to the Oregon Border. This section of SR 97 connects south central Washington with Oregon. Passing lanes are needed to allow fast moving passenger cars to safely pass trucks and recreational vehicles.

US 2 at Monroe – Construct 2-lane bypass of Monroe – US 2 and I-90 are the two mountain passes open year round that allow access to central and eastern Washington State. The town of Monroe has become a chokepoint for interregional travel due to access related problems from development and the proliferation of traffic signals on this section of US 2.

Events and recreation

Events such as a Mariners game, Bumbershoot, the holiday tree lighting in Leavenworth, WSU homecoming or travel to Washington's beaches can cause considerable delay in our transportation system at locations that do not ordinarily incur delay. These events and activities are part of what makes this area such a great place to live and are a big part of our local economies.

Example Projects

US 101 – Add passing lanes in strategic locations - US 101 is a much-used recreational route. It is a two-lane highway with limited passing opportunities. Installing passing lanes in strategic locations along with associated informational signing could help to reduce serious accidents in this corridor.

I-90/SR 18 Interchange – Improve interchange connections – This interchange fits in all four categories. In the winter it is used as a connection to ski areas and in the summer to hiking trails and other recreational opportunities.

SR 20 at SR 20 Spur – Replace intersection with interchange – This interchange is the gateway to Whidbey Island and Deception Pass State Park. The current at-grade connection is a chokepoint.

One way to look at the issue of competing bottleneck and chokepoint investment opportunities is to look for projects that perform multiple objectives. Limited funding makes it a necessity to find ways to increase the efficiency of funding dollars. Appendix 2: Examples of Targeted Bottleneck and Chokepoint Investments, provides a comparative illustration of projects based on how they fulfill multiple objectives.

Conclusions

Although there is an increasing amount of delay on our freeway system, not all of this delay is an indication of system inefficiency. As the freeway speeds drop below the posted speed limit, the throughput of the freeway increases until the speeds drop below the 45 to 50 mph range. To maximize the efficiency of the freeway system we need to keep the traffic flow above the curve (Figure 9). There are many ways to stay on top of the curve including:

- Operational measures, which control the number of vehicles using a lane (such as HOV lanes, ramp metering, or pricing);
- And capital investments, which expand capacity.

However, choosing where our limited funding should make capital investments is difficult because of competing interests such as: commuters (both general purpose and HOV traffic), freight haulers, cross state travelers, and users of major recreational activities. Making a decision on the policy of our investments is vital to the future planning of our system. The policy options indicated in this paper are intended to initiate a much needed debate on this topic and provide a starting point for discussion between WSDOT, the Transportation Commission, the Legislature and the citizens of the State.

Appendix 1: Measuring and Calculating Delay and Its' Cost

What is Delay?

Traffic delay is the difference between the amount of time that people expect to travel (usually traveling at the speed limit) as compared to their actual travel time (which is usually at some speed below the speed limit). Delay can be expressed as the total amount of hours delay experienced by all roadway users or by the average daily or annual amount of delay experienced by the individual roadway user. At some level of delay, users of the system consider the roadway "congested" and at some further level, people would define the roadway as "unacceptably congested". These levels of distinction vary between people in the same city, region, or state. Much of congestion measurement is based on individual perception as opposed to scientific calculations.

Calculating Delay

There are several tools available to calculate hours of delay: Real-time data (described in more detail below), travel demand models and various other spreadsheet tools. With the exception of real-time data, each of these tools uses volume and capacity as basic inputs.

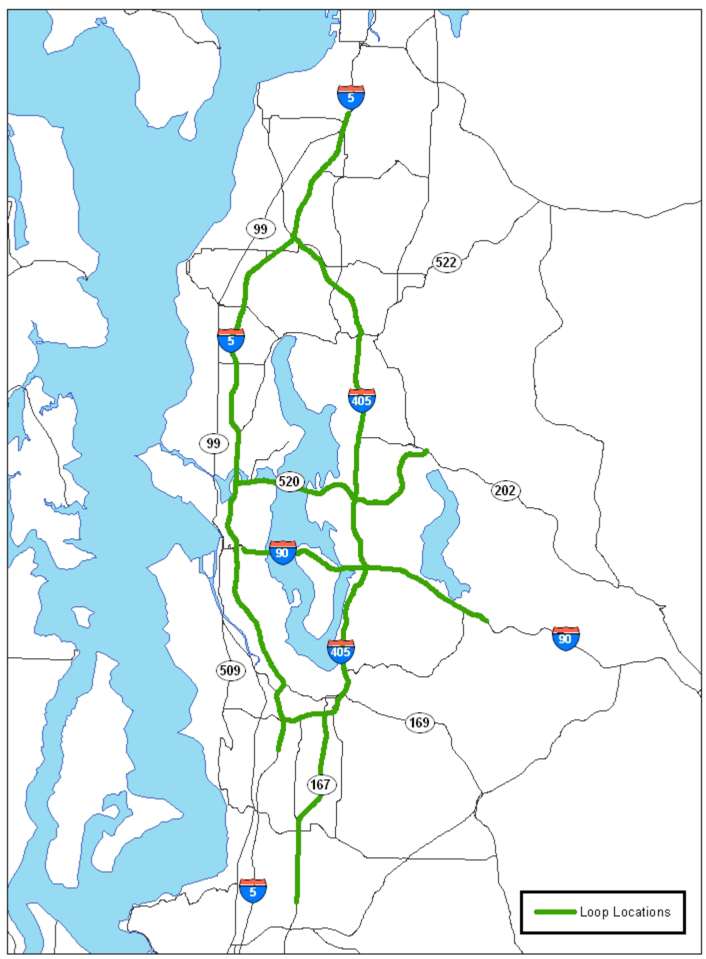


Figure A-1: Highways with Loop Detectors
Source: WSDOT

Real-time Data

Real-time data is collected by utilizing various technologies that measure traffic volumes, speeds and densities. In the Puget Sound Region, an extensive system of pavement embedded sensors, known as loop detectors, monitor traffic flow 24 hours per day, 7 days per week. The system that is covered by loop detectors is shown in Figure A-1.

Volume and speed are the only required inputs to calculate delay with real-time data. Since the volume and speed is measured continuously, no estimation is required. Delay is calculated any time the speed drops below a certain threshold (for instance, 60 mph on a freeway). Each vehicle that experiences these drops in speed is counted and a total delay for the system can be calculated.

In an ideal world, delay data would be generated using real-time data. The problem is that collecting information in enough locations to make this method usable on a large scale is very expensive. Furthermore, future real time data are not available. This is a situation in which a travel demand model can be utilized to estimate the speed and volume that then can be used to calculate delay.

Estimated Delay Based on Volume and Capacity

When real-time measurements are not available, empirical models have been developed to allow delay to be estimated based on travel volumes and roadway capacity. Most travel demand models have this type of estimator embedded in the program, which allows speeds and delay to be an output of the travel demand model. The delay estimator can also be a freestanding model, such as the WSDOT Travel Delay Methodology, which uses volumes and capacities as inputs and generates speeds and delay. In either case, these delay estimators use volumes and capacities as inputs, and use mathematical relationships calculated from real world data to estimate hourly traffic patterns, travel time, delay, and speed.

Existing traffic volumes can be collected through traffic counts or can be estimated using travel demand models. Future volumes are either estimated using travel demand models or are based upon historic growth rates.

The capacity for a freeway is significantly higher than that of a two-lane highway or urban arterial with dense signal spacing[18]. Table A-1 illustrates some basic capacity assumptions for various roadway types.

Table A-1: Basic Per-Lane Capacities

Freeway	2,000
Multi-lane Highway	1,800
Rural 2-Lane Highway	1,200
Signalized Arterial	800

Once you have volume and capacity inputs, travel times can be calculated using Volume-Delay Functions that predict what the travel speed will be at various volume levels. The concept is that as the volume increases, the travel speed will decrease. Volume/Speed relationships are not linear, so at lower volume levels the speed does not drop as rapidly as it does at higher volume levels[19].

[18] Capacities are generally calculated using the Highway Capacity Manual.
[19] For further discussion on this topic, please refer to the latest Highway Capacity Manual published by the Transportation Research Board of the National Research Council.

By using the speeds predicted from a volume-delay function, the vehicle hours of delay can then be estimated for a highway segment. The total hours of delay can be generated with the following formula:

Vehicle Hours of Delay (VHD)

VHD = Actual Vehicle Hours Traveled (VHT) – Free-Flow VHT

Where:

Actual VHT = Calculated Travel Time * Volume
Free-Flow VHT = Travel Time at Threshold Speed * Volume

This delay can be calculated for individual segments of roadway and then summed up for the state, region, city, etc. The measurement of delay can also vary based upon the point at which congestion is considered to begin. In transportation planning delay is typically measured from the posted speed limit. However, it is possible to measure delay from an starting point desired by the user of the model. All results from this method are for recurring delay[20].

Estimating the Cost of Delay

The cost of congestion is made up of three basic components.

- The cost of wasted time.
- Vehicle operating costs.
- The cost of accidents.

The Cost of Wasted Time

The amount of time that motorists spend in slow-moving traffic could be spent in other ways. Economists provide insights into the economic values of these lost “opportunity costs” by suggesting techniques for determining how much people would be willing to pay to be able to have the time that they were stuck in traffic available for whatever they would most like to be doing with it.

The value of people’s time spent in traffic can vary based on their circumstances. For instance the motorist with three passengers missing the first three innings of the Mariners game for which they had paid for prime box seats may have a very different answer to “how much would you pay not to be in this traffic jam” than two kids on their way to hang out at a mall on Saturday afternoon. A broker late to show an expensive house to an interested client might have a different answer than someone driving to meet a friend for coffee at Starbucks. There are also shippers whose expensive drivers and trucks cost “real money” when they are delayed, and who may in fact see actual lost value to their cargo if deliveries are not made when promised.

[20] For more information on measuring recurring and non-recurring delay, refer to a recent research report conducted by Washington State Transportation Center (TRAC) titled “Measurement of Recurring Verses Non-Recurring Congestion.”

There are many different viewpoints and theories about how to arrive at calculations of these many, varying, individualized "costs". WSDOT, drawing on the approaches used in widely-accepted economic studies, uses the following estimation tools[21]:

- For work-commute trips, 60% of the average local wage rate.
- For all other personal motorist trips, 50% of the average local wage rate.
- For commercial trips, a rate of $50 per hour of delay, based on driver wages and a factor for a presumed vehicle "rent". No value is assigned to the economic cost to consumers or businesses for late delivery, a clear limitation of the model.

The Cost of Wasted Fuel and Vehicle Operating Costs

Many vehicle operating costs, such as fuel, go up the more often a vehicle is used. The cost of operating a vehicle can be measured on a per mile basis or converted to hourly costs based on average travel conditions. Costs that do not vary with usage, such as insurance, storage and financing, are not included in this cost. An example of the vehicle operating costs used in WSDOT's current priority programming work is shown in Table A-2.

Table A-2: Vehicle Operating Costs

	Operating	*Ownership**	*Total*
Vehicle Operating Cost per Mile – Autos	$0.12	$0.30	$0.42

* Assumes 12,000 miles per vehicle annually.

Source: User Benefit Analysis for Highways, American Association of State Highway Transportation Officials, 2003, page 5-10 and based on *Your Driving Costs,* American Automobile Association, 1999. Updated to 2003 dollars by Parsons Brinckerhoff.

[21] Studies that WSDOT has consulted at in arriving at the following values include: A 1996 paper by Ted Miller entitled "The Value of Time and the Benefit of Time Savings"; concluded that the "cost of time" for a driver should be 55 percent of the wage rate and 40 percent for passengers, regardless of trip purpose or a passenger's mode choice. An analysis of twenty studies conducted since 1960 show that a range of 50 to 75 percent of the wage rate is typically used in benefit analysis. A US Department of Transportation publication entitled "The Value of Travel Time: Departmental Guidance for Conducting Economic Evaluations" (1997, revised 2003) has provided similar guidance using 50 percent of the average wage rate for personal travel and 100% for business travel.

Appendix 2: Examples of Targeted Bottleneck and Chokepoint Investments

The following list is illustrative of projects that remove bottlenecks and chokepoints in a particular area, thereby reducing delay for one or more of the following types of users: commuters (both general purpose and HOV traffic), freight haulers, cross state travelers, and users of major recreational activities. The list has been separated into the different regions across the state. Additional explanations are available for the projects in bold print following the list of statewide projects.

Location	Commute GP/Transit	Freight	Cross State	Events & Rec.
Eastern Washington				
I-90 – Argonne Road to the east – Adds lane capacity in stages.	**X**	**X**	**X**	
SR 20 – Sherman Pass – Add strategic passing lanes		X	X	X
SR 195 –Pullman to Spokane – Strategic widening and intersection improvements.	**X**	**X**		
North Central Washington				
SR 97 – Blewett Pass – Additional passing lanes		X	X	X
SR 97 – Wenatchee to Omak – Strategic passing lanes		X	X	X
SR 28/SR 285 – Approaches to George Sellars Bridge – Improve connections	**X**	**X**		
South Central Washington				
I-82 at Valley Mall Blvd. Interchange reconstruction	X	X		
SR 17 in Moses Lake – Widening in targeted locations		X		
I-90 at Snoqualmie Pass – Provide avalanche protection		**X**	**X**	**X**
SR 97 – Satus Pass – Additional passing/truck climbing lanes		X	X	
Southwest Washington				
I-5 in the Chehalis Vicinity – Add lanes to I-5 – phased approach		**X**	**X**	**X**
I-205 – SR 14 to Mill Plain Blvd. – Add auxiliary lanes	X	X		
SR 500/SR 503 Intersection – Improve intersection geometry	X			

Location	Commute GP/Transit	Freight	Cross State	Events & Rec.
Olympic Peninsula				
US 101 – Add passing lanes in strategic locations		**X**		**X**
I-5/US 101 Interchange – Improve interchange connections	X	X		X
US 101/SR 8 Interchange – Improve interchange connections		X		X
Northwest Washington				
SR 20/I-5 Interchange – Reconstruct interchange	**X**	**X**	**X**	**X**
I-5 through Mount Vernon – Add capacity to I-5	X	X	X	X
SR 20 at SR 20 Spur – Replace intersection with interchange	X	X		X
Central Puget Sound				
I-405 – Spot I/C improvements & lane additions throughout corridor	X	X	X	
SR 167 – Puyallup to Auburn – Complete HOV lanes	X	X		
SR 167 – S. 180th to 84th Ave. S. – Add auxiliary lanes	X	X		
I-5 Industrial Way direct access transit ramp	**X**			
SR 99 at 1st Ave. S. – Improve connection across 1st Ave. S.	X	X		
SR 509 at Port of Tacoma – Improve connection into the Port		X		
SR 519 – I-5 to SR 99 – Implement Phase 2 to improve Port connection		X		
US 2 at Monroe – Construct 2-lane bypass of Monroe	**X**	**X**	**X**	**X**
US 2 at SR 204 – Improve interchange connections	X	X	X	X
I-90/SR 18 Interchange – Improve interchange connections	**X**	**X**	**X**	**X**
SR 522/SR 104 Intersection – Improve intersection channelization	X			
SR 161 – Southhill Mall area – Signal timing and access management.	X			
I-5/SR 16 Interchange – Improve interchange connections	**X**	**X**		**X**

Location	Commute GP/Transit	Freight	Cross State	Events & Rec.
SR 9 – North of US 2 – Improve major intersections	X			
I-5 at Port of Tacoma Road – Interchange reconstruction		X		
SR 162 – SR 410 to Orting – Add GP capacity in phases	X			X

SR 20/I-5 Interchange – The current interchange configuration requires a number of unusual maneuvers to access I-5 from SR 20. It has long been a problem location affecting commuters, freight haulers, and recreational users of the SR 20. For part of the year, SR 20 also serves cross state travel. More direct connections to I-5 have been developed and should be implemented.

I-5 Industrial Way Direct Access Transit Ramp – Transit vehicles traveling on I-5 have difficulty accessing the dedicated transit lane (a lane reserved exclusively for transit known as the E-3 Busway) that parallels I-5 to the west and takes buses directly into the Seattle Bus Tunnel. This direct access transit ramp would create I-5 connections to and from the south allowing transit better access between I-5 and the busway.

I-90/SR 18 Interchange – The I-90/SR 18 interchange is rapidly becoming a significant bottleneck due to increased commuter traffic mixing with the already heavy freight traffic in this corridor. It is becoming more common for drivers to go out of their way to use SR 18 in order to avoid congestion on I-90 and I-5. Recent development on Snoqualmie Ridge, in addition to the increase in drivers avoiding more common routes, makes improvements to the I-90/SR 18 interchange a necessity. Direct ramp connections from I-90 to SR 18 should be constructed over time, building those with the greatest traffic demand first.

I-5/SR 16 Interchange – These two heavily traveled corridors serve commute, freight, and recreational travel. They are connected by a poorly functioning interchange. With funding from the 2003 Legislative Transportation Funding Package to construct HOV lanes on I-5 and SR 16, the interchange becomes an even greater bottleneck. Construction of an improved interchange that provides direct freeway-to-freeway connections is needed.

Appendix 3: List of Tables and Figures